Dynamically Driven Phase Transformations in Damaged Composite Materials

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A model developed for composite materials undergoing dynamically driven phase transformations in its constituents [1] has been extended to allow for complex material microstructure, viscoplasticity, and evolution of damage.

In this work, damage is described by interfacial debonding and microcrack growth. Here we have applied the analysis to silicon carbide-titanium (SiC-Ti) unidirectional metal matrix composites. In SiC-Ti composites, Ti is the matrix and SiC is the reinforcement with their volume fractions being 65% and 35%, respectively. This composite has shown potential use in aerodynamics applications due to its excellent properties especially at elevated temperatures. However, the phase transformation of Ti from α(hcp) to ω(hex) phase, viscoplastic flow, cracking in SiC, and debonding at the interface of SiC and Ti complicate its behavior. Understanding these phenomena is important in extending the usage of this material.

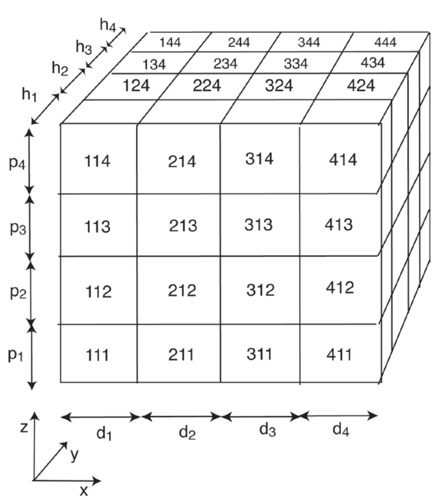

Fig. 1.
Unit cell of GMC with 4x4x4 subcells: in the simulations discussed, (112), (212), (312), (134), (234), and (334) are SiC.

First we examined each process independently in order to understand their characteristic behaviors, which appear in a more complicated way when applied simultaneously. In order to accommodate the highly anisotropic behavior of composite materials, we adopted the micromechanical framework, or more specifically, the Generalized Method of Cells (GMC) as our analysis tool. Because micromechanical analysis does not require *a priori* assumption on the behavior of the composites (instead it does the equation of state of each constituents), it is favorable in treating elastoplastic composites or damaged material where anisotropy plays an important role in determining local load and resulting flow (Fig. 1).

With these extensions we have carried out simulations to study the complex interplay between loading rates (Fig. 2), microstructure, viscoplasticity, damage, and the thermomechanical response of the system as it undergoes a solid-solid phase transformations (Figs. 3 and 4). In conclusion, the performance of the SiC/Ti composite is certainly superior to pure Ti, as it can endure higher loading. Because there is not any experimental data available for the regime of the phase transformation, we have performed detailed consistency tests on our analysis.

We hope this work inspires experiments to be performed on this composite. Further refinements of this model include implementing shear deformation, tangential debonding, and crack opening. Also other types of phase transformation, (e.g., melting) can be studied by this method.

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[1] F.L. Addessio, et al., "A Model for Heterogeneous Materials including Phase Transformations," *J. Appl. Phys.* **97**, 083509 (2005).

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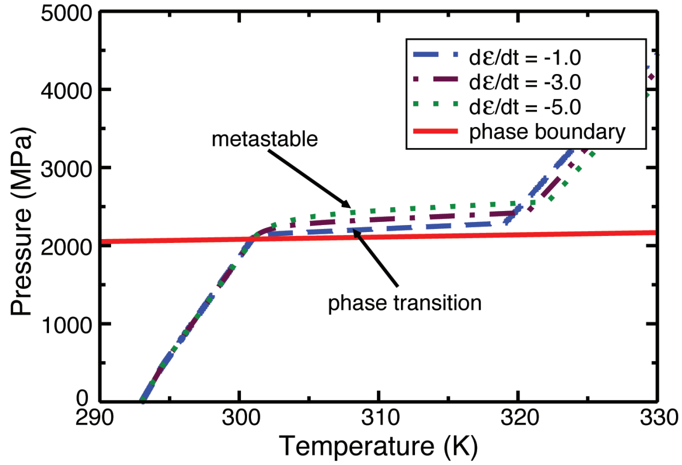

Fig. 2.
The effect of strain rate on phase transformations of Ti; uniaxial strain with τ = 3.0 m2 s.

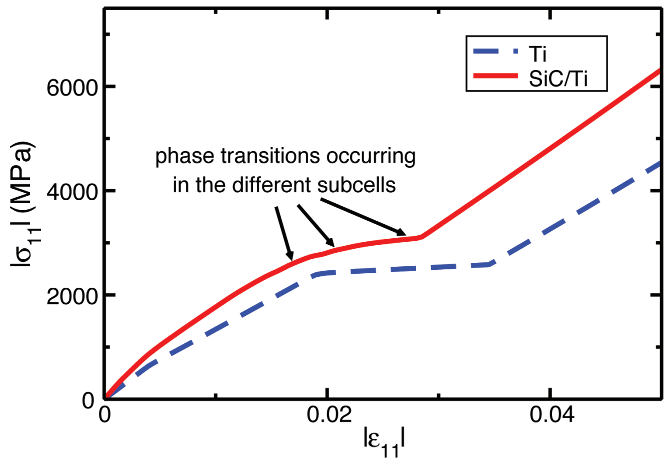

Fig. 3.
The phase transformation in SiC/Ti composite.

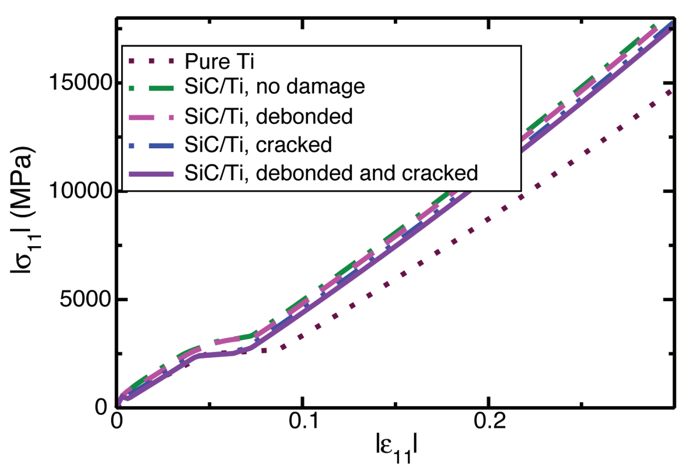

Fig. 4.
SiC/Ti composite with the phase transformations, viscoplasticity, cracking, and debonding.